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## Emerging Applications of LiDAR / Airborne Laser Scanning in the Management of World Heritage Sites

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## **Emerging Applications of LiDAR/ Airborne Laser Scanning in the Management of World Heritage Sites**

### **AUTHORS**

William P. Megarry (Corresponding Author)<sup>1</sup>

ELEVATE Government of Ireland Scholar, Cultural Site Research and Management,  
Baltimore Maryland

Department of Applied Mathematics and Statistics, Johns Hopkins University

Bryce A. Davenport

Senior Remote Sensing Specialist, Cultural Site Research and Management, Baltimore  
Maryland (b.davenport@culturalsite.com)

Douglas C. Comer

President, Cultural Site Research and Management, Baltimore Maryland  
(d.comer@culturalsite.com)

Fellow by Courtesy, Whiting School of Engineering, Johns Hopkins University

### **KEYWORDS**

World Heritage Management, Archaeological Landscapes, Airborne Laser Scanning, Site  
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<sup>1</sup> Now Lecturer in Geographical Information Science, Geography, Archaeology and Paleoecology, Queens University Belfast, Elmwood Ave, Belfast BT9 6AY. Email: w.megarry@qub.ac.uk Ph. +44 28 9097 5283

## AUTHOR BIOGRAPHIES

### **William Megarry**

William Megarry is Lecturer in Geographical Information Science at Queen's University Belfast. He recently completed an ELEVATE Government of Ireland Postdoctoral Fellowship at University College Dublin based in Baltimore, Maryland, with Cultural Site Research and Management and The Johns Hopkins University Department of Applied Mathematics and Statistics, developing tools to detect and manage cultural heritage using aerial and satellite remote imagery. He has a PhD in GIS and Archaeology.

### **Bryce Davenport**

Bryce Davenport is a GIS Specialist and archaeologist with Cultural Site Research and Management (CSRM), and has an MA from Brandeis University. He has worked with CSRM and the CSRM Foundation on research projects funded by the NASA Research Opportunities in Solid Earth Science (ROSES) program, the US Department of Defense Legacy program, and governments of Peru, Moldova, Sudan, the Dominican Republic, and the United States, and has co-authored a number of articles and reports based upon this work.

### **Douglas C. Comer**

Douglas C. Comer is President of Cultural Site Research and Management (CSRM) and the CSRM Foundation and served as Principal Investigator for many of the projects described in this article. He is also President of the International Council on Monuments and Sites (ICOMOS) International Committee on Archaeological Heritage Management (ICAHM), Vice-Chair of the United States ICOMOS National Committee, and a member of the Governing Board of the UNESCO International Centre on Space Technologies for Natural and Cultural Heritage (HIST). A Fulbright Scholar in cultural resource management, he served for 15 years as Chief of the United States National Park Service Applied Archaeology Center and nine years as Chair of the Maryland Governor's Advisory Committee on Archaeology. Dr. Comer is Senior Editor of the Conservation and Preservation Section of the Encyclopedia of Global Archaeology, Senior Editor for the Springer Press/ICAHM publication series Multidisciplinary Perspectives in Archaeological Heritage Management, a Fellow at the Whiting School of Engineering, The Johns Hopkins University, and Visiting Independent Advisor with the NASA Jet Propulsion Laboratory at Caltech

(JPL/NASA). He has authored or edited several books and numerous journal articles and other publications on archaeology, aerial and satellite remote sensing, and heritage management, and has consulted or provided management, planning, and interpretive services on these topics in many countries on all continents, frequently at World Heritage Sites.

## ABSTRACT

Remotely sensed data and imagery have revolutionized the way we understand archaeological sites and landscapes. LiDAR/ airborne laser scanning (ALS) has been used to capture the often subtle topographic remnants of previously undiscovered sites even in intensely studied landscapes, and is rapidly become a key technology in survey projects with large extents and/or difficult terrain. This paper examines the practical application of this technology to archaeological heritage management, with special attention to how ALS can support the World Heritage List nomination process and management of WHS archaeological sites and landscapes. It presents a number of examples from published ALS studies alongside case studies from projects undertaken by the authors at Cultural Site Research and Management and The Cultural Site Research and Management Foundation, Baltimore, Maryland, USA. The paper opens with a review of how ALS has been used at established World Heritage Sites, focusing on the Archaeological Ensemble of the Bend in the Boyne, Ireland and the Angkor Archaeological Site in Cambodia. ALS applications for site prospection and demarcation, and Viewshed analysis is explored in this section. Following this, we will explore how ALS has been used to support two recent applications: the successfully nominated Monumental Earthworks at Poverty Point, USA and the recently nominated Orheiul Vechi Archaeological Landscape in Moldova. We propose that the detail offered by ALS data greatly strengthens nomination dossiers by emphasizing the outstanding universal value of sites, highlighting significant features and providing greater context to wider landscapes, and is particularly efficacious in delineating site boundaries for legal protection and long-term management. Finally, we conclude with a look at some of the practical considerations involved in the use of ALS including access and training.

## PAPER STRUCTURE AND OVERVIEW

### PART I - INTRODUCTION

#### Introduction

This paragraph introduces the term ALS and the current state-of-the-art in archaeology. It makes a case for the publication as a specific piece focusing on ALS as applied to WHS. It also outlines the four examples which will be used in the paper.

#### Airborne Laser Scanning - An Overview

This section provides a brief overview of the technical aspects of ALS including basic terminology. It explores resolution and the different between returns. Surface models and derivatives useful for prospection are then introduced.

### PART II - ALS AND WORLD HERITAGE

#### Some Uses of ALS for Management of World Heritage Sites

This section explores why ALS should be used at world heritage sites with a particular focus on legislation. It sets up the context for the paper's case studies by proposing three primary uses for ALS: site prospection, inventorying and management applications (for both research and day-to-day management purposes) and research into the OUV of sites.

#### ALS at Established WHS: Ongoing Research and Inventorying

This section introduces the ALS project at Angkor and how it can be used to answer long-standing research questions about already well-studied sites. It also explores how ALS has been used for inventory work done at the Brú na Bóinne. This section continues exploring how ALS was used at the Brú na Bóinne, focusing on viewsheds from the primary sites in the WHS. A more recent example of a similar exercise from the 2015 Stonehenge, Avebury and Associated Sites World Heritage Site Management Plan is also presented.

### ALS at Tentative WHS: Boundary Demarcation and Studies of OUV

The availability of ALS data from non-archaeological sources is discussed here. It is suggested that, while not ideal, this data can still be very useful in the nomination process. Boundary demarcation is a key part of the nomination process. This section presents results from an ALS survey project undertaken as part of the dossier for the nominated (pending) site of Orheiul Vechi, Moldova. Establishing the OUV of a prospective WHS is essential to inscription. This section explores how ALS data can be used to explore this OUV at Poverty Point, USA, using viewshed analysis to explore the spatial syntax of the landscape.

## PART 3: ALS AND WHS: SOME PRACTICAL CONSIDERATIONS

### ALS and WHS: A Review

This section summarizes the key points from the article; specifically, the value of ALS in border and boundary demarcation, and its ability to add to the OUV of tentative and established WHS.

### ALS: Access and Training

This section will explore some of the practical considerations around using ALS at WHS including access and training. It will suggest that there is considerable cost-benefit in obtaining and using ALS at WHS, and suggest some avenues for funding access and training.

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## PART 1 - INTRODUCTION

### Introduction

The application of airborne laser scanning (ALS) - more commonly known as light detection and ranging or LiDAR - to world heritage sites (WHS) is explored in this paper. The acronym ALS is preferred which differentiates between terrestrial laser scanning devices like total-stations (TST) and airborne platforms which mount sensors on aerial devices (after (Opitz & Cowley 2013)). The state-of-the-art of ALS as applied to archaeological landscapes has been reviewed in two recent volumes (Harrower & Comer 2013; Opitz & Cowley 2013). Unsurprisingly these have focused on both methodology and prospection, however a number of chapters record applications at World Heritage Sites, including two examples from Ireland at the Bend in the Boyne and at Skellig Michael (Megarry & Davis 2013; Corns & Shaw 2013). ALS has been collected and used at a number of WHS. Results from these projects are spread across specialist journals and publications but none approach how ALS may be applied specifically in a WHS context. Some of these applications are discussed and presented in this paper, including using ALS for archaeological site prospection and inventorying and boundary demarcation, and how high-resolution elevation data can be used to further understand the outstanding universal value (OUV) of sites through visibility analysis. Two well-known examples of ALS applications at established WHS are reviewed at Angkor, Cambodia and the Bend in the Boyne (Bru na Boinne), Ireland. The potential role of ALS in the nomination of new properties is then explored using examples from the tentative (nomination pending) WHS at Orheiul Vechi, Moldova and the recently inscribed property at Poverty Point, USA.

### Airborne Laser Scanning - An Overview

*It should be an overriding principle that the gathering of information about the archaeological heritage should not destroy any more archaeological evidence than is necessary for the protectional or scientific objectives of the investigation. Non-destructive techniques, aerial and ground survey, and sampling should therefore be encouraged wherever possible, in preference to total excavation.*



ICOMOS Charter for the Protection and  
Management of the Archaeological Heritage (1990) Article 5.

ALS sensors capture elevation values as cartographic 3-dimensional points using lasers, a sensor and geographical positioning systems (GPS). The laser is emitted and the sensor records the precise distance between itself and the object or point being measured. A GPS is then used to locate that point in Cartesian space. Most ALS systems can record multiple elevation values in very close proximity to each other and each value is called a 'return'. When the laser is reflected before it reaches the ground, the value is called the 'first return'. The final reflection is called the 'last return', and this point often represents the ground surface. First returns can be anything from power lines to tree canopy, and despite the very fine resolution of most ALS instruments it should be stressed that ALS *cannot* penetrate foliage or structures themselves, and so last returns do not necessarily reach ground level. If foliage is dense, transmitting many points of light per square meter can increase the probability that some will reach and be reflected by ground surface, but does not guarantee it. For this reason, autumn or winter ALS recording is preferable for regions with deciduous forests. The number of points captured will affect the final resolution of the dataset. While the resolution of ALS varies considerably, it is now possible to get surface models which capture terrain elevation every 10 cm. The resolution, and often the ability to record points beneath vegetation, will initially depend heavily on two technical factors: the instrument or system, and the platform. There are a range of ALS systems including discrete return platforms which capture a single point, and the more detailed full waveform ALS which captures the intensity of the signal at regular intervals. These systems can be carried on different platforms like helicopters, airplanes, and unmanned aerial vehicles. The speed of the vehicle can influence the capture speed and the resolution of the data captured. An enormous amount of data is captured which needs to be filtered and cleaned before it can be used. During this post-processing stage returns are classified between first and last. This process is time-consuming and requires a great deal of care, especially when processing data from archaeological landscapes where low-lying features can be inadvertently misclassified.

Terrain models are surfaces (rather than points) which allow users to visualize topography. Digital terrain models (DTM) record the first ALS returns while digital surface models (DSM) record the last or final returns. The elevation data in these models can be used in a GIS for modelling, including hydrological studies and visibility analysis (for a good overview of raster analysis in GIS

see (Conolly & Lake 2006). It is also possible to generate derivative models which can be used for archaeological prospection - much of the recent literature on ALS has focused on these surfaces. Hillshade and multi-directional hill shading model the shadows cast by sunlight from different angles and orientations (Challis et al. 2011). These shadows can exaggerate even low lying topographic features. Other derivatives include Skyview factor which is an estimate of the visible area of sky from a terrestrial viewpoint, and can be used to avoid the pitfalls of direct illumination techniques by providing 'diffuse lighting' visualization (Zakšek et al. 2011). Rugosity or terrain ruggedness has been a common geographic calculation for decades and frequently sees use in land-form and/or -cover classifications. Local relief modeling (LRM), here used after Hesse's implementation in Baden-Württemberg, targets these small scale elevation changes more aggressively by actively classifying physiographic changes out of the visualization with low-pass filtering (Hesse 2010). These derivatives all have the same purpose - to identify topographical features which represent archaeological activity. The efficacy of each technique will differ based on the landscape but together they represent a tried and tested toolkit for remote prospection using ALS.

It should be stressed that ALS is best applied as part of a prospective remote sensing toolbox. ALS primarily detects topography and is limited to monuments or earthworks which retain some, albeit slight, surface presence. It cannot detect subsurface remains like geophysical survey, nor can it provide information on soil moisture or plant health like multispectral imagery. It can also be limited by dense foliage or water. While a powerful prospective tool, ALS is only part of a bigger toolset.

## PART II - ALS AND WORLD HERITAGE

### Some Uses of ALS for Management of World Heritage Sites

*The protection of the archaeological heritage must be based upon the fullest possible knowledge of its extent and nature. General survey of archaeological resources is therefore an essential tool in developing strategies for the protection of the archaeological heritage.*

*...The compilation of inventories should therefore be regarded as a continuous, dynamic process. It follows that inventories should comprise information at various levels of significance and reliability, since even superficial knowledge can form the starting point for protectional measures’.*

ICOMOS Charter for the Protection and  
Management of the Archaeological Heritage (1990) Article 4.

Inventorying archaeological heritage is a central part of WHS management; both for tentative and established properties, but there are other important management applications. Outside of WHS management, site prospection remains the most powerful application of ALS. Finding sites is often presented in popular media as an end in itself, one that carries with it magical overtones. Yet aerial photograph have been used to find thousands of archaeological sites for a century. ALS simply provides the means by which to detect sites based upon terrain, thus providing a new tool, but as with any tool, its value depends upon the ends to which it is put.

By identifying and adding new sites to accessible state databases, they can be considered in planning applications and damage mitigation. Knowing the location of features in a landscape can also facilitate zoning or boundary demarcation. In a WHS context, ALS can be used both during the nomination process, and for the continued study of current properties. Article 88 of the World Heritage Convention (hereafter WHC) Operational Guidelines 2015 stresses that, in order to accurately show a property’s integrity, the extent of a WHS must be of sufficient size to ‘ensure

*the complete representation of the features and process which convey the property's significance'* ( WHS Operational Guidelines 2015, Article 88). The establishment of clear buffer zones is also an essential part of the inscription process. These zones should be large enough to ensure that the authenticity and integrity of the property is protected from developments. ALS can be a valuable tool in establishing both boundaries and buffer zones. An example from the tentative site of Orheiul Vechi, Moldova is discussed below.

For inscribed properties, Article 4 of the ICOMOS Charter for the Protection and Management of the Archaeological Heritage stresses the importance of survey as a dynamic and ongoing process. Enriching the site inventory is of course central to the ongoing management of any site in a greater landscape context and this management premise has been behind the identification of countless new archaeological sites and features at places like Bru na Boinne, Ireland and Angkor, Cambodia. Both of these examples will be discussed in this section. ALS has been collected at some of the most important WHS. One of the earlier examples focused on the Stonehenge landscape, where the authors noted the potential of ALS for site prospection and inventorying. They also realized that ALS provides more than just a tool for prospection; it can also be used to facilitate the management of archaeological landscapes. They noted that, *'The composition of management plans and conservation plans, in particular, are enriched by lidar information and the facility for demonstrating the historic assets of landscapes in a highly accessible manner is of the greatest value to resource managers'* (Bewley et al. 2005). Enriching the site inventory is of course central to the ongoing management of any site in a greater landscape context and this management premise has been behind the prospection of countless new archaeological sites at places like Bru na Boinne, Ireland and Angkor, Cambodia. Both of these examples will be discussed in this paper.

ALS prospection has been used to answer specific research questions about important landscapes. From a WHS perspective, it can also be used to better understand the importance or OUV of a landscape. This process is essential for nominations to the World Heritage List and an example from the recently inscribed property at Poverty Point, USA is presented in this paper. For properties inscribed before 1998, a retrospective statement of OUV is required and insights from ALS studies can inform these statements (WHC Operational Guidelines 2015, Paragraphs 154 – 155). When OUV is already well established, ALS can be used for the ongoing monitoring and study of WHS. This is especially true in densely forested landscapes like at Angkor,

Cambodia where ALS has captured information on architecture and urban growth of the site, much of which is under dense foliage. Obtaining such information using traditional methods would be time-consuming to the point of redundancy.

The detail captured by ALS enables researchers to ask questions at a previously unavailable *anthropogenic scale* (Golden & Davenport 2013). Earlier datasets like the elevation models collected as part of the Shuttle Radar Topography Mission (SRTM) or those collected by the ASTER platform captured data at 90 and 30 meters. This resolution was too coarse to answer specific questions on visibility at a local landscape scale - questions which can be both archaeologically and practically informative, especially in landscapes like the Brú na Bóinne where monumental earthworks have significantly modified the structure and spatial syntax of the prehistoric landscape. This scale also allows site managers to explore the visible impact of contemporary activities on World Heritage Sites. This is increasingly important as more and more WHS are at risk from urban encroachment.

#### ALS and Established World Heritage: Ongoing Inventorying and Research

ALS can be a powerful tool at even the most intensely studied WHS. ALS surveys at numerous WHS have time and again shown the efficacy of the technology to further understand even the most well-studied properties.

Angkor, Cambodia - The site of Angkor was inscribed on the world heritage list in 1993 on the basis of criteria (i), (ii), (iii) and (iv) in the hope that the inscription process would promote expedient conservation at the site (WHC-92/CONF .002/12, 34-35). The site was an extensive urban center and capital for of the Khmer Empire, and was constructed between the 9th and 15th centuries. The site now receives over two million visitors per year who come to visit the ornately decorated temples. It remains the subject of intense academic research.

In 2012, a 370 km<sup>2</sup> ALS survey was undertaken of the landscape around Angkor in northwest Cambodia (Evans et al. 2013). Full waveform ALS data was captured at a resolution of four to five points per square meter. Following processing, ground returns with a resolution of two points per square meter were used to generate a digital terrain model which was in turn used to create

derivative surfaces like hillshade and localized relief models (Hesse 2010). Results were truly amazing and transformed how scholars understood the city at Angkor and its hinterland. The known extent of the city increased from 9 km<sup>2</sup> to 35 km<sup>2</sup>, with streets, temples and vernacular buildings visible over a huge area, organized in a highly formalized cardinally aligned grid. It was also possible to trace the spatiotemporal evolution of the cityscape around a complex and highly structured water management system. At Angkor ALS was not just used for site prospection, it was used to answer long-standing questions about the size, organization, rise and decline of the site. It should be noted that results from ALS need to be interpreted as part of a larger research framework as it cannot provide specific information on chronology. ALS allows us to see what is there, but it takes a trained eye to interpret it. There can be little doubt that this study significantly added to the OUV of the site, specifically elements which contribute to the original WHS selection criteria.

The Archaeological Ensemble of the Bend in the Boyne, Ireland - The World Heritage Site at the Bend in the Boyne in Ireland was inscribed on the World Heritage List in 1993 on the basis of criteria (i), (iii) and (iv). The Bru Na Boinne is an inhabited agricultural landscape, where modern farming practices exist side-by-side with megalithic archaeological sites. Construction in and around the WHS has necessitated evaluations by UNESCO and national organizations keen to maintain the outstanding universal value of the landscape while respecting local communities and development (WHC-SOC-2760; (D. C. Comer 2011). This uneasy balance was noted at inscription, where UNESCO invited the Irish Government to carefully monitor future developments in and around the site (WHC-93/CONF .002/LD.2).

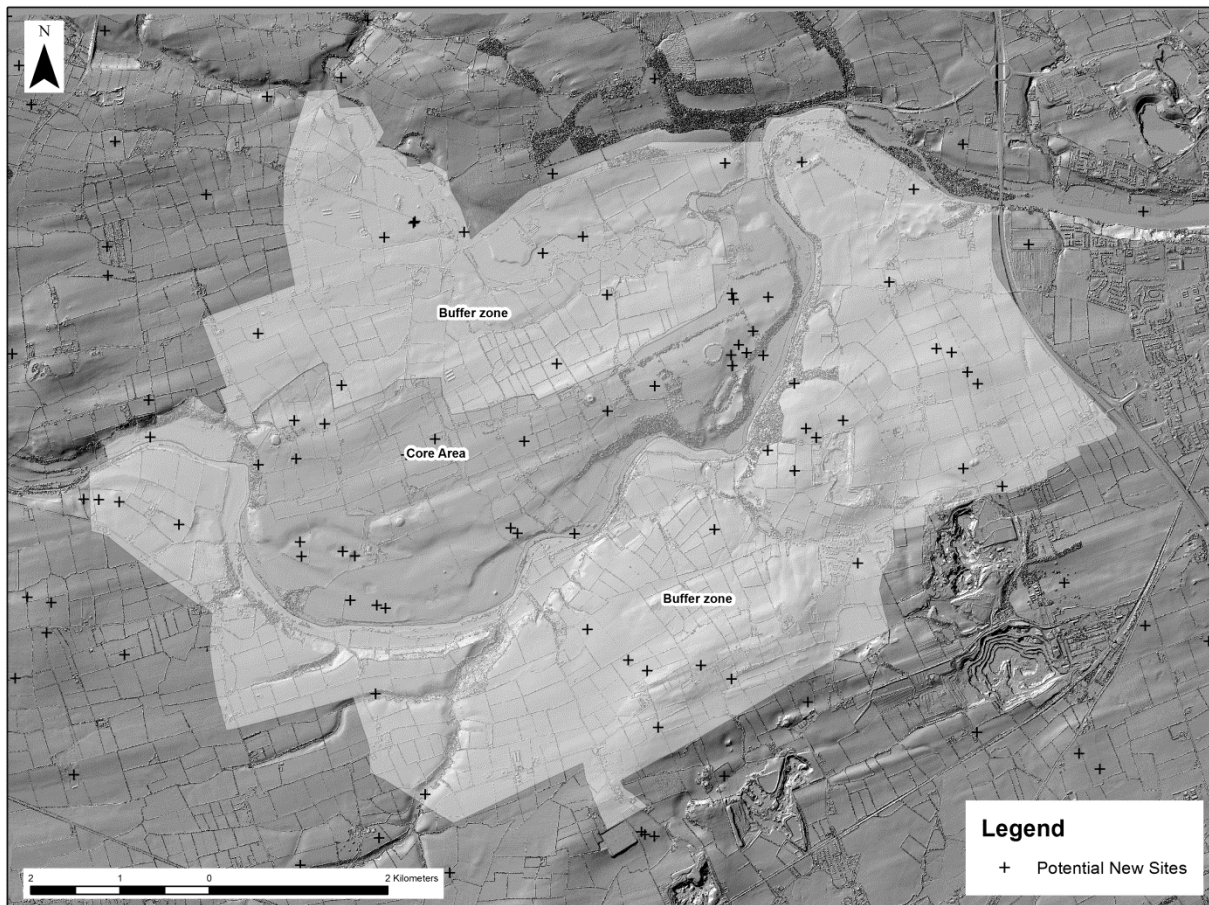


Figure 1: Potential New Sites in the Bru na Boinne WHS. Data from the INSTAR Boyne Valley GIS Project (Davis et al. 2010).

In 2007, ALS data was collected for the WHS covering an area of 96 km<sup>2</sup>. This data was used to generate a digital surface, and digital terrain model of the landscape. This was part of a larger campaign to record Ireland's inscribed and tentative WHS sites using ALS (Corns & Shaw 2013). The data was widely shared between governmental and academic institutions leading to the discovery of over one hundred new sites (Figure 1), including many within the core area of the WHS (Megarry & Davis 2013; Davis et al. 2013). The significance of these results should not be understated. The identification of so many new sites, including some of considerable stature, within the most intensely studied landscapes in Ireland shows the prospective efficacy of the technology. They also strengthen our understanding of the archaeological landscape and

consequently the boundaries of the inscribed site. The 2009 Research Framework for the WHS suggests that the ALS data could be used to reassess the boundaries of the core area of the site, especially to the south where there has been some confusion (Smyth et al. 2009).

WHS Operational Guidelines state that buffer zones should include *‘the immediate setting of the nominated property, important views and other areas or attributes that are functionally important as a support to the property and its protection’* (WHC Operational Guidelines 2015 Article 104). The Brú na Bóinne landscape is low-lying with a gentle gradient. As a result, even subtle changes to the environment can have a significant impact on viewsheds to and from key locations. ALS was used to explore both prehistoric and contemporary viewsheds (Davis et al. 2010). Studies of changing viewshed along the course of the river, and the impact of construction in and around the WHS were explored, and significant areas identified (Figure 2). The visual dominance of the three great tumuli at Newgrange, Knowth and Dowth extends beyond the immediate landscape to important contemporary regional sites. The ALS was also a key component of the 2009 research framework (Smyth et al. 2009) and continues to be used by Meath County Council for viewshed analysis. The recently published Stonehenge, Avebury and Associated Sites World Heritage Site Management Plan 2015 noted that, *‘The inter-visibility of sites is an important attribute of the OUV which should be maintained and protected. Improvements in technical capabilities have meant that this can be graphically represented more easily’* (Simmonds & Thomas 2015). Actionable items on the management plan include restoring viewsheds by removing fences and other obstacles. Modelling these changes is now possible using high resolution ALS and the plan published detailed visual sensitivity maps of key monuments within the WHS. Maps record the visual sensitivity from key sites in the WHS, including Stonehenge and Avebury, using cumulative viewshed analysis.



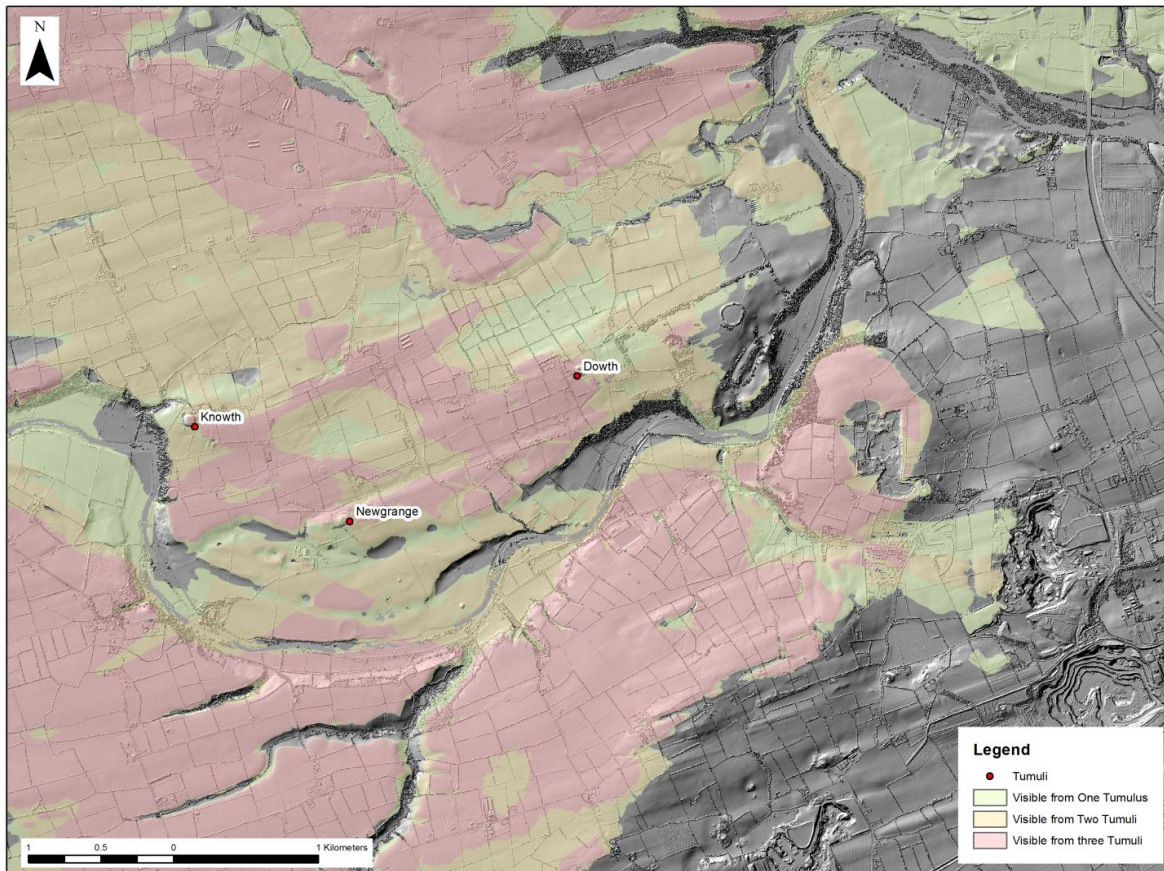


Figure 2: Viewsheds from the Three Main Tumuli, Bru na Boinne WHS. Data from the INSTAR Boyne Valley GIS Project (Davis et al. 2010)

### ALS and Tentative World Heritage: Boundary Demarcation and Studies of OUV

Given the cost of collecting ALS, it is unsurprising that examples often focus on well-known landscapes like Stonehenge, Angkor or the great urban centers of Central America (Bewley et al. 2005; Evans et al. 2013; Chase et al. 2011). The above examples all focus on high profile sites where ALS was flown specifically for heritage management and prospective purposes. There are obvious benefits to this. Data can be collected at an appropriate resolution and then post-processed carefully and sympathetically to archaeological features. Increasingly however, ALS data is available for lesser known archaeological landscapes from non-archaeological sources. Data collected for environmental and infrastructural projects can often be used for cultural

resource management and damage mitigation, and can play a key role in the nomination of tentative sites to the World Heritage List. While there is often little control over resolution, the considerable benefit to using this data will be explored in this section by looking at case studies from Orheiul Vechi, Moldova and Poverty Point, USA.

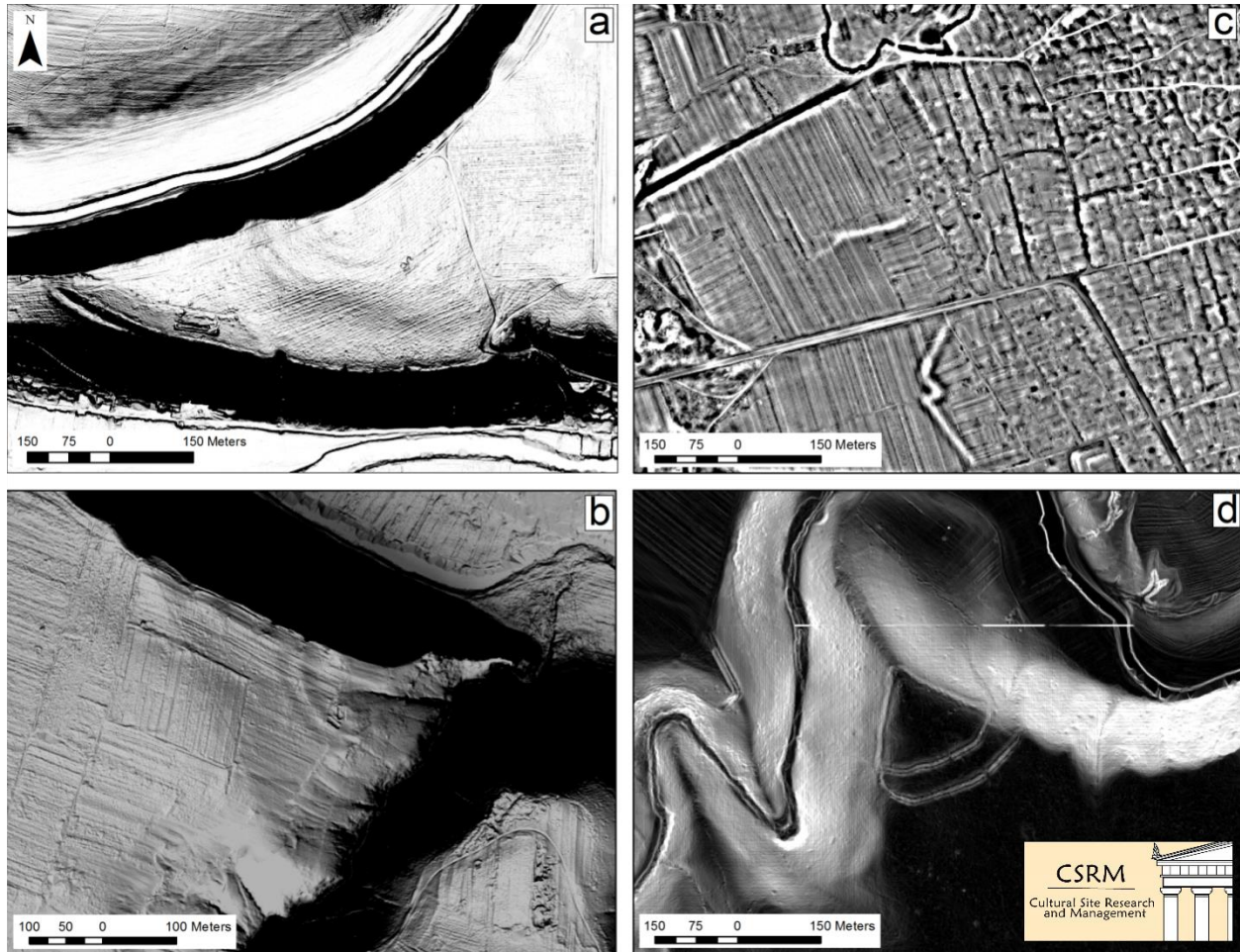


Figure 3: Comparison of surface derivatives and highlighted features. a. Circular feature, possibly a ringfort, in composite hillshade. b. Known promontory fort in sky-view factor with hillshade transparency. c. Linear feature, possibly a moat or dike corresponding to medieval fortifications of the adjacent village, in local relief model. d. Known promontory fort in ruggedness index.

Orheiul Vechi, Moldova - The site of Orheiul Vechi, Moldova, has recently (2015) been re-nominated to the World Heritage List after an unsuccessful bid in 2008 (WHTL-5937). Orheiul Vechi occupies a meander of the Răut River, a Dniester tributary, and holds a commanding position over Black Sea routes into Eastern Europe. It served as a focal point for Iron Age Geta-Dacian, monastic Christian, Mongolian, and early modern Moldovan occupations in the region. Under nomination category [v], Orheiul Vechi shows a longstanding engagement with natural fortifications and is a focal point for Post-Soviet Moldovan identity. If accepted, Orheiul Vechi will be the first World Heritage Site in Moldova.

During the intervening years between the two nomination attempts, a flood-risk survey along the Răut was undertaken by ASTEC Geodata using ALS. Cultural Site Research and Management (CSRM) Baltimore, was employed by the Moldovan Ministry of Culture to develop a robust remote sensing component for the new nomination dossier, and our team reprocessed this data into a 1 meter resolution digital elevation model. In addition to extensive hillshading, a variety of more sophisticated surface derivatives were employed, which proved effective because of the prevalence of linear features and the soil history of the area (Figure 3). While many parts of the Orhei region had implemented 'deep tilling' agricultural practices in the Late Soviet era, conditions which can occlude small elevation changes and patterns, it is notable that ALS was still remarkably effective in identifying previously unknown archaeological sites

Several new inventory objects, all sizable fortifications and defensive walls that would have figured importantly in the long history of disputes over the strategic trade location occupied by Orheiul Vechi, were revealed during this analysis. Among the most surprising was a large, semi-circular feature that appears to be one of the principal Iron Age fortifications at Orheiul Vechi in an area that received frequent traffic and has been investigated by conventional, on-ground archaeological surveys and excavations for decades (Figure 4). While the power of ALS to reveal features in difficult terrain has been demonstrated at Angkor and in other tropical environments (Bewley et al. 2005; Evans et al. 2013; Chase et al. 2011), the high sensitivity of derived surfaces to small, sometimes miniscule, patterns in well-traversed landscapes holds greater importance for many World Heritage properties - areas that, in most cases, have been exhaustively investigated through traditional methods.



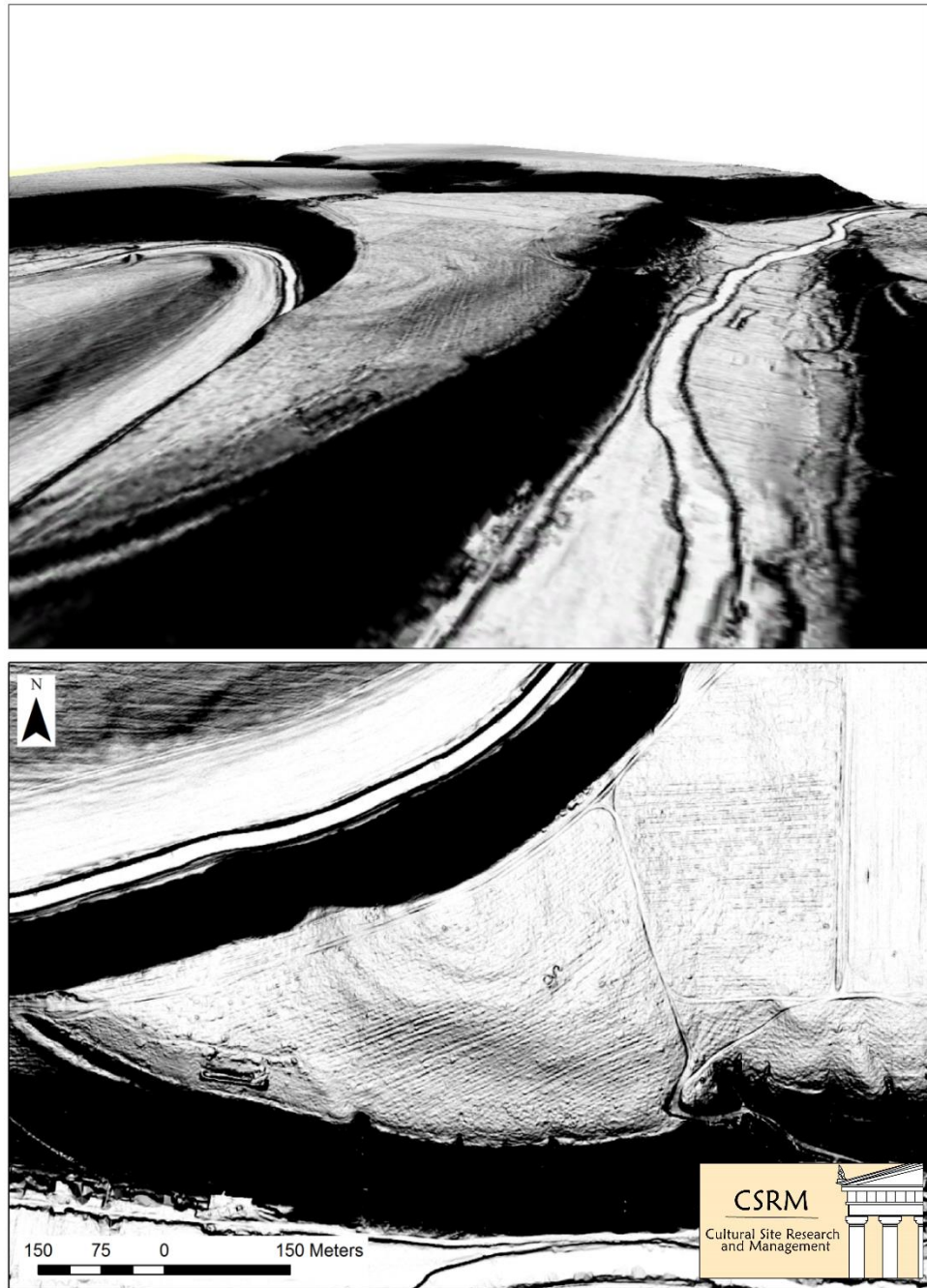


Figure 4: Semi-circular feature at Orheiul Vechi, Moldova

Two key management objectives were taken from this ALS application that formed a core part of the new nomination dossier. First, the site inventory demonstrated the ongoing need to protect the landscape in its entirety given the significant numbers of features that were previously not known to be there, a key component of the justification narrative. The nomination dossier notes that within *“this sanctuary are more than 1000 archaeological structures, including settlements, cemeteries, churches, caves, mosques, caravanserais and dwellings. Among these, more than 300 have undergone limited testing by archaeologists...”* (Moldovan Ministry of Culture 2015: 161), highlighting the tension between documentation needed to substantiate OUV and the mandate to preserve property resources *in situ* to retain the integrity of the site for visitors. In properties that are not defined by extant, monumental structures, this tension is more palpable. Cooney ((Cooney 2007; Cooney 2009) notes that the strong representation of walled towns and cities in World Heritage List nominations implicates a particularly European initial ideal of heritage that is continuously being negotiated by new nomination criteria, categories, and justifications. Remotely sensed ALS data strengthen claims of OUV without necessitating destructive analysis, to some extent resolving the contradiction between OUV and integrity that can appear in archaeological contexts.

Second, the documentation of previously unknown features allowed us to revisit the boundaries established for the protection of the site. Comparisons of feature density, size, and relationships to previously known sites suggested modifications to the existing boundaries that are currently under review, although the core area corresponds very well to both the old and the newly documented concentration of features. One new feature outside of the proposed buffer zone is a prime candidate for future acquisition, and it is pertinent that the data used in this study were originally collected for flood risk estimates. The creation and management of buffer zones is one of the areas most in need of sophisticated surface analysis to understand the potential impacts of tourist amenity development that inevitably follows WHS status - new understandings of feature distribution, as seen here and at Angkor, can suggest a need for boundary enlargement, while changing terrain through construction of roads, buildings, and other hospitality services can drastically affect risks from local hydrology.

Poverty Point, USA - The monumental earthworks of Poverty Point was inscribed on the World heritage List at the 38th session of the World Heritage Committee in Doha in 2014 (WHC-14/38.COM/16). It was inscribed under criterion (iii) as an outstanding testimony to a cultural tradition which has since disappeared. Constructed by hunter-fisher gatherers between 3700 and 3100 BC, the complex consists of mounds and six semi-elliptical earth ridges (Greenlee et al. 2013). The tallest feature on site, Mound A, is one of the largest and oldest earthen constructions in North America. The visual impact of these structures on the landscape is significant at both a regional and local scale, and as part of the nomination process, The Cultural Site Research and Management (CSRM) Foundation, Baltimore undertook a study on the spatial syntax of the landscape in support of the nomination dossier (Comer & Wimbrow 2012). This study used the ALS collected in 2008 by 3001 International Inc. as part of a state-wide collection project funded by the Federal Emergency Management Agency and private insurance companies, and was distributed by the LSU CADGIS Research Laboratory in Baton Rouge, Louisiana (Cunningham et al. 2002). In comparison to aforementioned examples, the data collected was very coarse with a resolution of just 5 meters. Viewshed and least-cost pathway analysis were used to explore approaches to the earthworks from the river and indicated the sudden appearance of the monuments as visitors crest a ridge 200 meters from the dock (Figure 5). While Mound A would have been visible up to 20 km away when approaching by land, a riverine approach would have concealed the earthworks until the last moment. Given the scale of the site, this effect must have been awe inspiring to early visitors and further strengthens Poverty Point's claim as a unique testimony to the Late Archaic cultures who constructed it. This data was incorporated into the Nomination dossier where the ALS was also used as part of a GIS to generate strong images. The use of ALS at Monumental Earthworks of Poverty Point shows that even coarse data collected for ulterior motives can be used to strengthen a nomination, by providing an otherwise unavailable perspective on the archaeological landscape.

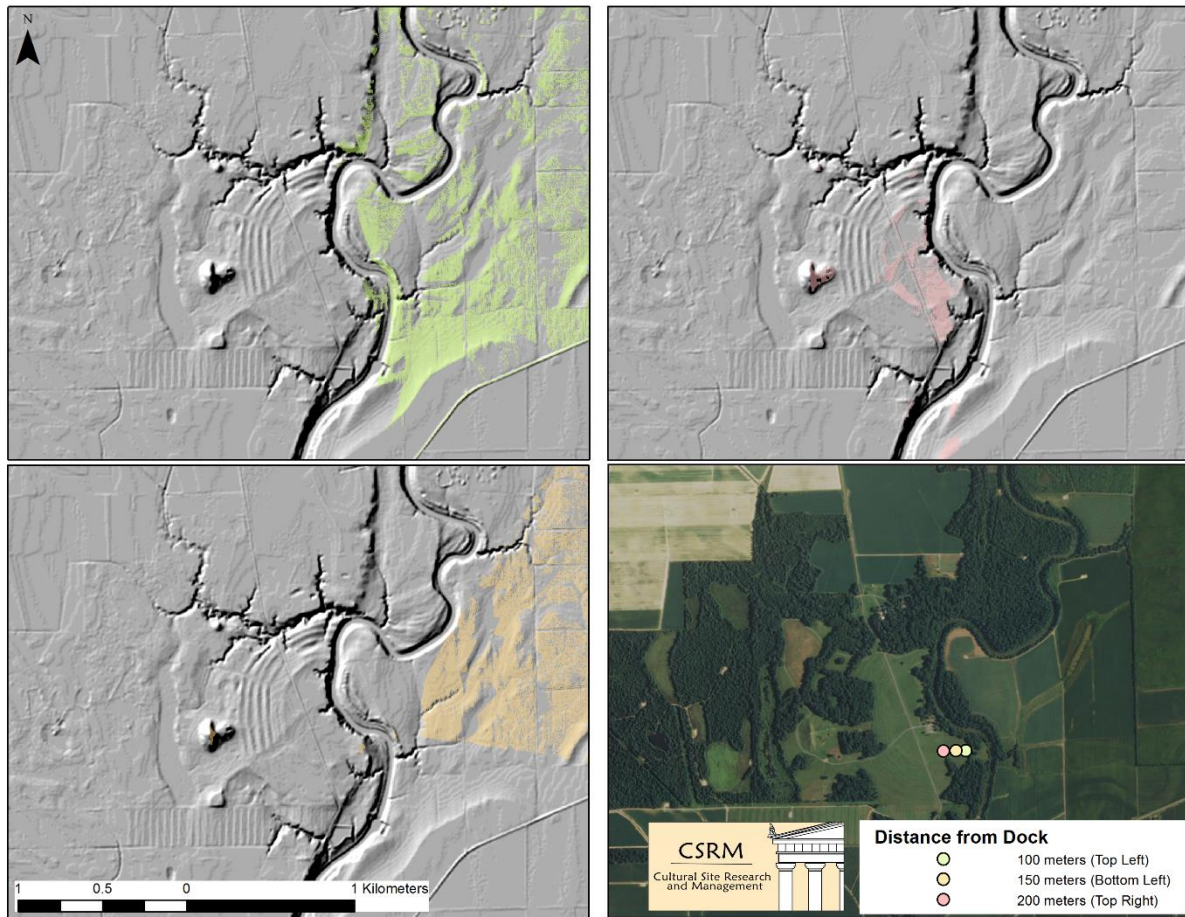


Figure 5: Changing Viewshed upon approach to Mound A, Poverty Point WHS

## PART 3: ALS AND WHS: SOME PRACTICAL CONSIDERATIONS

### ALS and WHS: A Review

The benefits adduced from the inclusion ALS for WHS management both during and after the nomination process share a core set of attributes: the noninvasive nature of the technology, high fidelity of the data, and the ability to produce a series of question-oriented surface models. The ongoing benefit of ALS will be reviewed in this section, as will a brief discussion on accessibility and training.

One of the most important factors in successful management of heritage properties is the institution of adequate boundaries, buffers, and zones, with context-appropriate uses clearly defined for each. For many WHS, however, understanding of the full extent of the cultural remains is an ongoing process, while new waves of development can render buffer dimensions inadequate. The example from Orheiul Vechi has shown how such prospection and demarcation can be used to demark boundaries and buffers for inscription. Examples from two intensely studied WHS sites at Brú na Bóinne and at Angkor show how ALS was used to identify hundreds of new sites and archaeological features. Establishing and clarifying boundaries is a key concern to UNESCO. At Petra, boundaries were only finalized in 2015 after decades of pressure (WHC-SOC-1894), while the boundaries at Brú na Bóinne were updated in 2008 (32 COM 8D). At Angkor at the time of inscription, the committee stressed the importance of defining site boundaries, effective management zones and accompanying regulations, a task fully completed in 2006 (WHC - SOC - 1181). ALS is a powerful tool for border and boundary demarcation at both tentative and inscribed WHS.

As seen at both Poverty Point and Orheiul Vechi, ALS also has the ability to strengthen nomination dossiers through increased understanding of the tangible and intangible qualities of the properties. Whether through the discovery of new features within a well-studied landscape or explaining how existing features relate to the landscape at larger scales, the inclusion of ALS analyses as a part of the nomination process can make an eloquent (and non-destructive) case for OUV without disturbing the integrity of extant structures and deposits.



## ALS: Access and Training

Cost remains a major factor for many properties and States. Acquiring ALS is currently an expensive proposition - instrument rental, flight chartering, and processing can range from tens to hundreds of thousands of dollars. Especially in those areas that do not currently boast thorough representation on the World Heritage List, the cost in domestic terms is untenable. Some specialized funding sources have been created to address funding issues, such as the National Science Foundation's National Center for Airborne Laser Mapping, an underwriter of Chase et al.'s (Chase et al. 2011) survey at Caracol, and in areas that can afford the initial outlay, the ultimate price of ALS is in many cases much cheaper and more effective than the equivalent landscape data gleaned from wide scale pedestrian survey. There are continued cost benefits to acquiring ALS. Corns and Shaw note that one of the unexpected benefits of using ALS at the Brú na Bóinne was that the overall quantity and quality of research improved. By making the data widely available, other projects were able to gain insights into landscapes which had already been intensely studied (Corns & Shaw 2013). Considerable effort is also being put towards developing lower cost UAV platforms for ALS instruments, which will drastically reduce the price of chartering flights. That said, at present it is still the case that data products are much more likely to arrive downstream from municipal studies or other engineering applications. For both the Orheiul Vechi and Poverty Point examples, the data were collected for disaster management. As mentioned above, the metadata for the Louisiana data collection the data collection was calibrated to produce 5 m digital elevation models and interpolated 2 foot bare earth contours, georeferenced to NAD83 horizontal and NAD88 vertical datum points (Cunningham et al. 2002). While we were unable to obtain the metadata for the Orheiul Vechi ALS data, it proved sufficiently high resolution to produce 50 cm and 1 m DEMs. In both cases the data were filtered to last returns to produce bare-earth digital terrain models. In this case re-processing was essential as protocols used for engineering often introduce considerable smoothing to the data, potentially classing out low-lying features. This paper has shown the value of this 'second hand' data in Moldova and the USA.

Historically, processing and visualizing data have been the purview of highly specialized experts either working in conjunction with archaeologists and heritage management professionals or data captured downstream from completely independent studies (i.e. engineering, development, disaster risk). The examples we present above straddle a significant skills gap - the Orheiul Vechi and Poverty Point nominations have taken advantage of incidental ALS data and outside

consultancies to bolster nomination prospects, while Angkor and Brú na Bóinne had customized ALS scans taken for explicit heritage management actions. As more and more World Heritage Sites use ALS, it is important that the technology becomes understood and implemented as a routine part of heritage management in the same way that GIS has been during the past two decades. Training is central to this implementation. One option for both training and obtaining ALS for sites in developing countries might be the UNESCO International Assistance fund. Under articles 13 and 19 to 26, the fund allows for training, and technical cooperation including equipment or experts for the conservation, management or presentation of sites. Conceivably, applicants could apply for funds to record ALS or, in cases where ALS exists, the fund could be used to train people to undertake the necessary analyses.

## CONCLUSION

This paper has reported on several applications of ALS at WHS. At the Bru na Boinne and Angkor, the use of ALS introduced the values of high resolution in visible analysis for planning purposes, making managers and other stakeholders aware of the persistence of archaeological sites and features on the landscape, the need to preserve them, and providing new insights into the relationships among previously known site and those discovered by the use of ALS. At Poverty Point space syntax analysis bolstered the nomination dossier for the site and suggested ways that the monumental earthworks there were used to organize the ancient societies that constructed them. ALS analysis was used to set boundaries at Orheiul Vechi for the area nominated to the World Heritage List and also for buffer zones. As with Poverty Point, ALS also provided material that strengthened the nomination dossier with the discovery of major forts and defensive walls dating to the Bronze Age and Medieval times. There are many other areas where ALS holds enormous potential. At Petra, Jordan, for example, an increase in impermeable surfaces outside of the buffer zone increased the force and volume of very modest seasonal rainfall drainage to deleterious levels, rapidly weathering the sandstone facades that make the site iconic (Douglas C. Comer 2011). ALS would provide a high resolution surface ideal for modelling solutions. While practical and financial obstacles remain, the ongoing cost-benefit of ALS at WHS is considerable and worth investment, representing an enduring investment for site management. ALS data sets can sometimes be obtained from organizations that have acquired

them for other purposes; in the future, such collaborations should become standard operating procedure.

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